NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1866

SPIN-TUNNEL INVESTIGATION TO DETERMINE THE EFFECTIVENESS OF A ROCKET FOR SPIN RECOVERY

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SUMMARY

The present paper presents a method, which makes use of the jet-reaction principle, for obtaining recovery from a spin during an emergency. The method proposed involves the installation on the airplane of rockets or jet units in order to provide sufficient yawing moment in an uncontrollable spin so that spin rotation will stop and, thus, the airplane will nose down to a point where control is regained.

Brief tests have been made of a dynamic scale model with a reaction rocket fired rearward from the inboard wing tip (right wing tip in a right spin) to provide a yawing moment against the spin. The spins were terminated rapidly and it appears that a properly selected jet-reaction device may be used for emergency spin recovery.

INTRODUCTION

Spin demonstrations are usually required for military airplanes before acceptance. During the spin demonstration a device for recovery from the spin in an emergency must be installed. In the past, spin-recovery parachutes, generally installed at the tail but sometimes installed at the wing tips, have been used. Necessary tests have been conducted in the Langley 20-foot free-spinning tunnel in order to determine the size parachute required to insure recovery from an otherwise uncontrollable spin. Based on empirical results obtained for 24 designs, a method of estimating the size parachute required has been proposed to the Armed Services (data unpublished).

Spin-tunnel experience has indicated that provision of an incremental yawing moment against the spin is very effective in terminating a spin. The method of estimating parachute size, which has been mentioned, is based on the premise that the effectiveness of a parachute for spin recovery depends upon its ability to provide a yawing moment. Provision of yawing moment by a parachute necessarily depends upon the direction the towline assumes during the spin and recovery, and parachute sizes required might become excessive for some configurations. The use of conventional parachutes also introduces serious problems in providing installations which will provide for satisfactory opening and satisfactory release. A method which provides a definite and direct increment in yawing moment appears to be needed as an alternate to the usual parachute installation.

Use of the jet-reaction principle is one method of applying a direct and adequate yawing moment during the spin. A device operating on this principle has been demonstrated by tests on a dynamic scale model in the Langley 20-foot free-spinning tunnel. The device used was a rocket which was fired rearward from the inboard wing tip (right wing tip in a right spin) in order to provide a yawing moment against the spin. (See fig. 1.)

SYMBOLS

b	wing span, feet
S	wing area, square feet
m	mass of airplane, slugs
$\bar{c}$	mean aerodynamic chord, feet
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet^2
$\frac{I_X - I_Z}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
V	full-scale rate of descent of airplane, feet per second
ρ	air density, slugs per cubic foot
α	angle between thrust line and vertical (approx. equal to absolute value of angle of attack at plane of symmetry), degrees (see fig. 1)
ϕ	angle of wing inclination between span axis and horizontal, degrees

F propulsive force of rocket, pounds

Ω angular velocity about spin axis, radians per second

Ω_Z component of angular velocity about airplane Z-axis, radians per second (approx. $\Omega \sin \alpha$)

N_R yawing moment developed by rocket force about normal body axis, foot-pounds

C_n yawing-moment coefficient $\left(\frac{N}{\frac{1}{2}\rho V^2 Sb}\right)$

METHODS

Analysis

Experience has indicated that recovery from a spin results if the yawing-moment equilibrium is upset by a sufficient application of yawing moment against the spin. (See references 1 to 5.) On the other hand, disturbances in the rolling- and pitching-moment equilibrium may be compensated for by changes in sideslip and rate of rotation. It therefore appears that recovery from the spin in a specified time will occur if the applied yawing moment is large enough. Experience in the Langley 20-foot free-spinning tunnel has indicated that spin recovery for a corresponding airplane will be satisfactory if the model recovers in two turns or less from a spin at normal-spinning-control configuration (rudder with the spin, elevator up, and ailerons neutral). A yawing moment large enough to bring about recovery of the model within two turns must, therefore, be applied.

In references 1 to 5, application of a yawing-moment coefficient C_n of approximately 0.02 by movement of the rudder was generally found to terminate the spin satisfactorily. Unpublished data have indicated that for recovery by parachute action alone, with the rudder maintained with the spin, the yawing-moment coefficient required for satisfactory recovery may vary somewhat from this value depending upon the vertical-tail design. Figure 2, which is based on the previously mentioned unpublished data, indicates that provision of a yawing-moment coefficient of approximately 0.025 would adequately terminate the spin for the model tested even though the rudder was held full with the spin.

The model dimensions were such that an application of a force at the wing tip of approximately 1200 pounds on the corresponding airplane would provide a yawing-moment coefficient of 0.025. Application of such a force for approximately 3 seconds was estimated to provide a sufficient impulse which would completely overcome the momentum of the spinning airplane about its yaw axis on the basis that this time is approximately equal to $\frac{I_Z \Omega_Z}{F\frac{b}{2}}$.

On the corresponding airplane, this time would correspond to a recovery well within 2 turns; thus the application of an impulse at the wing tip of approximately 3600 pound-seconds would apparently be satisfactory to terminate the spin. The corresponding impulse on the $\frac{1}{25}$-scale model was $\frac{1200}{(25)^3} \times \frac{3}{\sqrt{25}} = 0.077 \times 0.6 = 0.046$ pound-seconds, approximately.

Use was made of a small rocket in which was burned powder capable of an impulse of the order of 100 pound-seconds per pound if completely burned; thus to obtain an impulse of 0.046 pound-seconds, approximately 1/4 gram of the powder would be required. Because of the small size of the rocket required, consistent impulses were difficult to obtain. The manner of packing the powder and the manner in which it burned greatly affected the actual impulse obtained. By discharging the rocket on the end of a beam to which was attached a strain gage, the variation of the ratio of force to time was indicated and the impulse from such measurements appeared to vary from 0.04 to 0.10 pound-seconds. In general, it was not possible to slow down the rate of burning of the powder to a value which would lead to a small value of force. For the present tests, the time during which the force acted was approximately 1/32 second, which for an average impulse of 0.07 would lead to a corresponding airplane force of about 35,000 pounds. If the impulse obtained had, however, consisted of a smaller force acting through a correspondingly larger period of time, the rocket would probably have been equally effective in terminating the spin.

Model

The $\frac{1}{25}$-scale model used for the tests was constructed and prepared for testing by the Langley Laboratory. Photographs of the model with the rocket installed are shown as figure 3. The dimensional and mass characteristics of the airplane represented by the model are presented in table I.

The model was ballasted to obtain dynamic similarity to a corresponding airplane at an altitude of 15,000 feet (ρ = 0.001496 slug/cu ft). The rocket used for the tests was constructed at the Langley Laboratory. An electromagnetic remote-control mechanism was installed in the model to fire the rocket for recovery. Magnetic activation of the mechanism closed a battery circuit which caused a high-resistance wire running through the powder to burn and, thereby, set off the powder charge through a small nozzle in the small metal cylinder which constituted the rocket. A diagramatic sketch of the rocket and the electrical circuit used is shown as figure 4.

Wind-Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is similar to that described in reference 6 for the Langley 15-foot free-spinning tunnel except models are now launched by hand into the tunnel. With the controls set in the desired position, the model is launched with rotation into the vertically rising air stream. After a number of turns in the established spin, recovery is normally attempted by movement of controls by means of the remote-control mechanism. For the current investigation, as previously indicated, the remote-control mechanism activated the rocket. A photograph of the model spinning in the Langley 20-foot free-spinning tunnel is shown as figure 5.

DISCUSSION

The effectiveness of the rocket for spin recovery was investigated for a model with normal-spinning-control configuration. At this control configuration the angle of attack was approximately 45° and the wings were practically level. The rate of descent was about 250 feet per second, full-scale, and the angular velocity was approximately 1/2 revolution per second, full-scale. Recovery by rudder reversal alone or by rudder reversal followed by moving the elevator down was found to be unsatisfactory, from 5 to 8 turns being required on the model.

Several recoveries were made by rocket action with the impulse, as previously indicated, varying from 0.04 to 0.10 pound-seconds. All recoveries were rapid. Figure 6 shows a typical recovery in which the spin was terminated in approximately 1/4 turn. Use of such a device is, therefore, indicated to be effective for spin recovery. Although the spin-tunnel tests were made with the rocket fired from the wing tip, application of sufficient yawing moment at the tail would undoubtedly have been equally effective.

The spin-tunnel tests are of only a preliminary nature; full-scale research is desirable in order to determine fully the value of a rocket device for recovery from the spin and to reveal any operational difficulties. In this connection, a German paper (reference 7) indicates that a rocket was actually used in flight to get out of an uncontrollable flat spin into a steeper spin from which recovery by use of controls was possible. For these tests, the rocket was fired laterally from the side of the airplane near the tail.

Inasmuch as the Armed Services require that during spin demonstrations an appropriate emergency device be installed on the airplane, possible advantages of using a rocket device for recovery may justify its consideration. By determination of the yawing-moment coefficient required from figure 2, the amount of propulsive force required can be readily ascertained and a unit to give this force can be built. For example, an available cordite rocket weighing approximately 65 pounds and having dimensions which would allow for installation on the wings of an airplane is known to give a thrust of 1200 pounds for $3\frac{1}{2}$ seconds. This weight is of the same order of magnitude as that of a parachute installation and apparently has the added advantage of eliminating the dangers associated with opening and releasing a spin-recovery parachute.

CONCLUDING REMARKS

A method which makes use of the jet-reaction principle was presented for obtaining recovery from a spin during an emergency. This method involves the installation on the airplane of rockets or jet units in order to provide sufficient yawing moment in an uncontrollable spin so that spin rotation will stop and the airplane will nose down to a point where control is regained.

The results of tests made of a dynamic scale model with a reaction rocket fired rearward from the inboard wing tip indicated that the use of a properly selected jet-reaction device should afford a reliable and positive method for emergency recovery from the spin.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., February 1, 1949

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7. Höhler, P., and Köppen, J. v.: Versuchsflüge zur Erprobung eines Rückstossers als Hilfsmittel zum Beenden gefährlichen Trudelns. FB Nr. 1027, (Berlin-Adlershof), 1939.

TABLE I.- FULL-SCALE VALUES OF THE DIMENSIONAL AND MASS CHARACTERISTICS OF THE $\frac{1}{25}$-SCALE MODEL

Wing span, ft	42.50
Length over all, ft	36.1
Propeller diameter, ft	13
Wing:	
Area, sq ft	322.2
Incidence, M.A.C., deg	1
Aspect ratio	5.51
Dihedral of wing, deg	6
Mean aerodynamic chord, in.	91.84
Leading edge M.A.C. rearward of leading edge of root chord, in.	6.74
Flap chord, percent wing chord:	
Inboard	25.78
Outboard	26.48
Ailerons:	
Chord rearward of hinge line, percent wing chord:	
Inboard	14.07
Outboard	19.40
Area rearward of hinge line, percent wing area	8.62
Span, percent wing span	39.37
Horizontal tail surfaces:	
Total area, sq ft	55.00
Span, ft	16.01
Elevator area, total, sq ft	22.00
Distance from normal center of gravity to elevator hinge line, ft	22.52
Vertical tail surfaces:	
Total area, sq ft	25.80
Rudder area, total, sq ft	11.92
Distance from normal center of gravity to rudder hinge line, ft	22.73
Unshielded-rudder volume coefficient	0.00979
Tail-damping ratio	0.0200
Tail-damping power factor	201.7×10^{-6}
Weight, lb	16,396
Center-of-gravity location, $x/\bar{c}$	0.300
Moments of inertia, slug-ft^2:	
I_X	16,335
I_Y	18,011
I_Z	33,519

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TABLE I.- FULL-SCALE VALUES OF THE DIMENSIONAL AND MASS

CHARACTERISTICS OF THE $\frac{1}{25}$-SCALE MODEL - Concluded

Inertia parameters:	
$\frac{I_X - I_Y}{mb^2} \times 10^{-4}$	-18
$\frac{I_Y - I_Z}{mb^2} \times 10^{-4}$	-168
$\frac{I_Z - I_X}{mb^2} \times 10^{-4}$	186
Relative airplane density:	
Sea level	15.6
15,000 ft	24.9

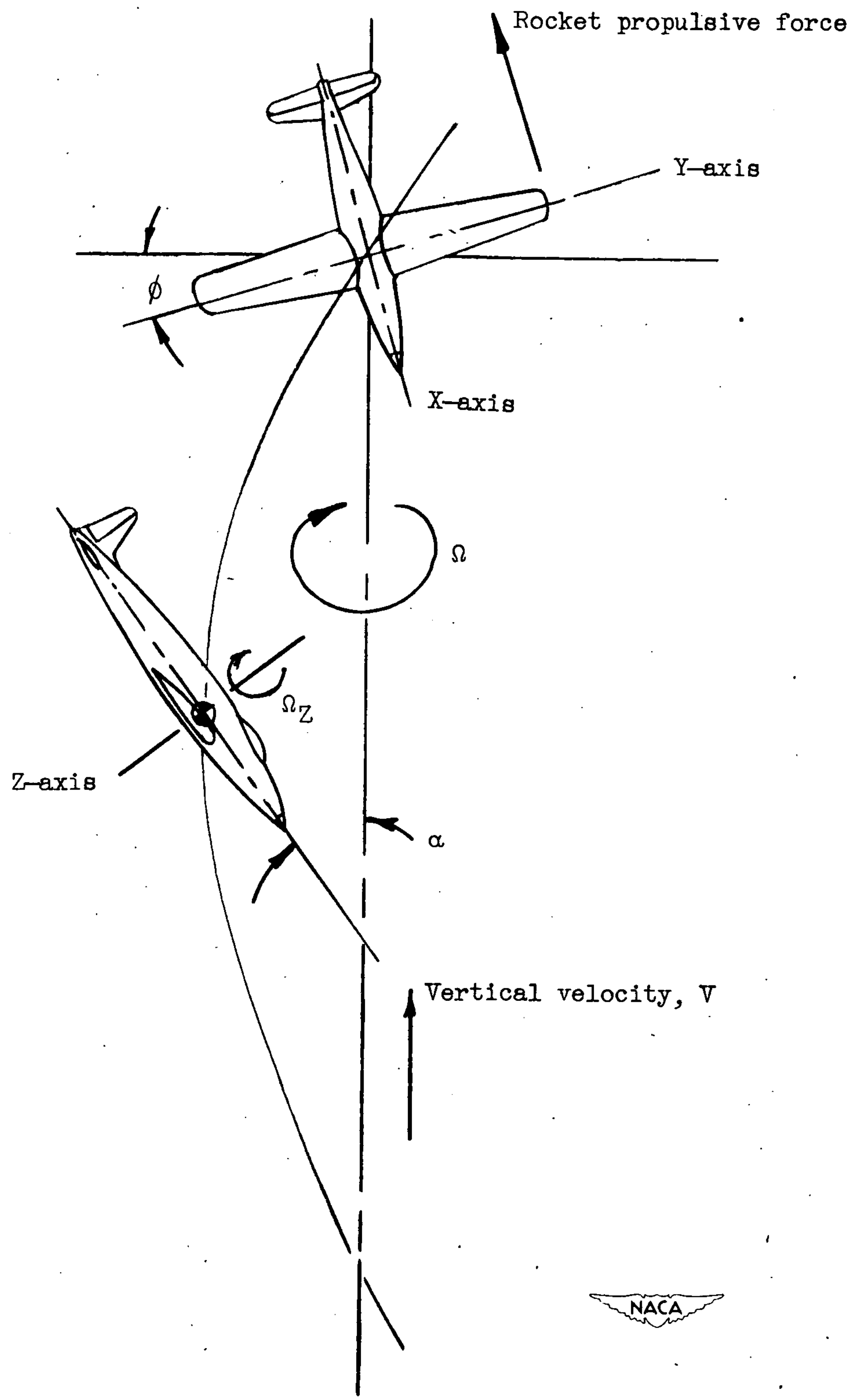

Figure 1.- Diagramatic sketch showing motion of an airplane in a right spin and the direction of the propulsive force of the rocket during recovery.

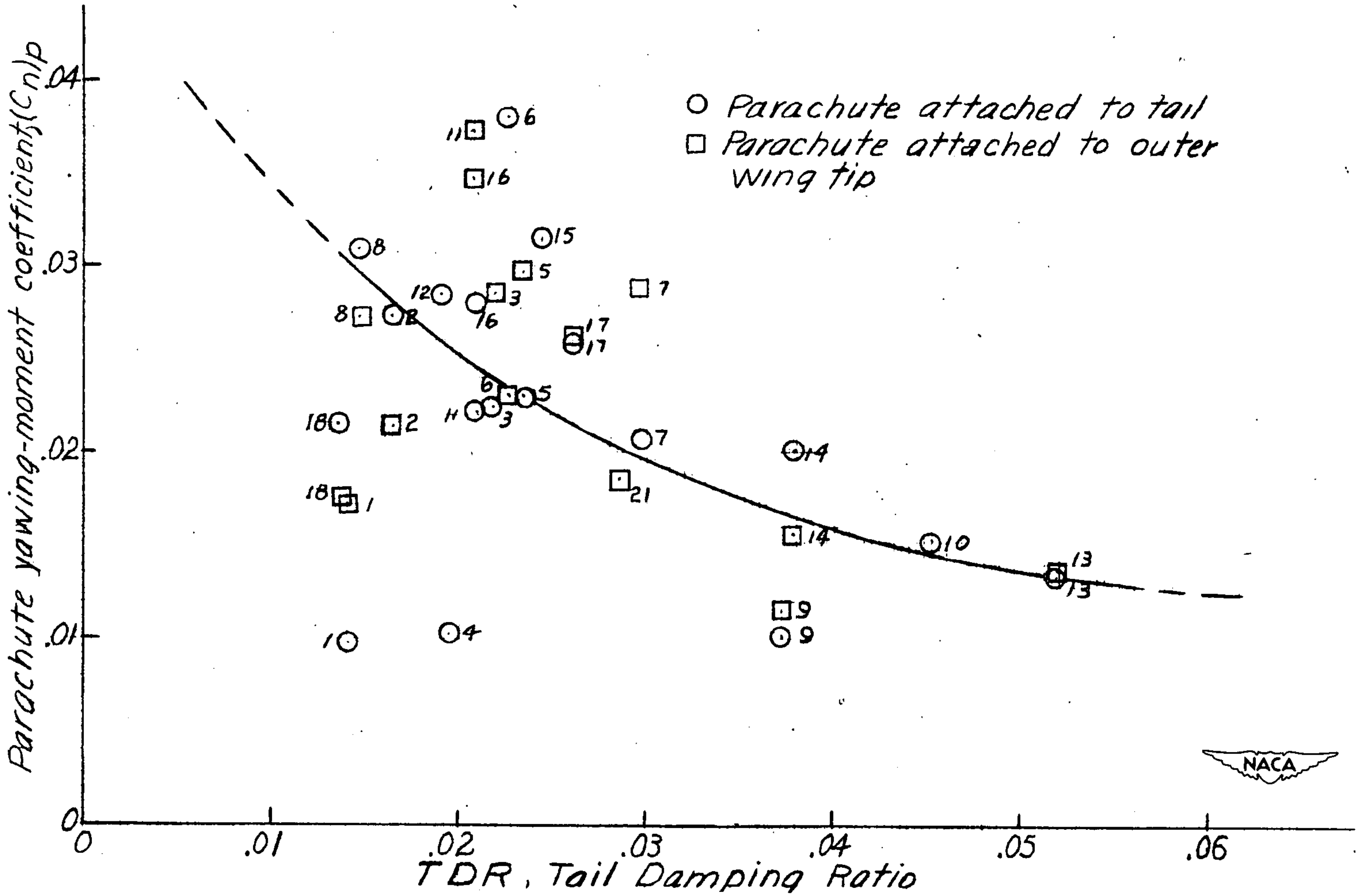

Figure 2.– The variation of parachute yawing-moment coefficient $(C_n)_p$ required for satisfactory recovery from the spin by parachute action alone with the tail damping ratio TDR of the airplane.

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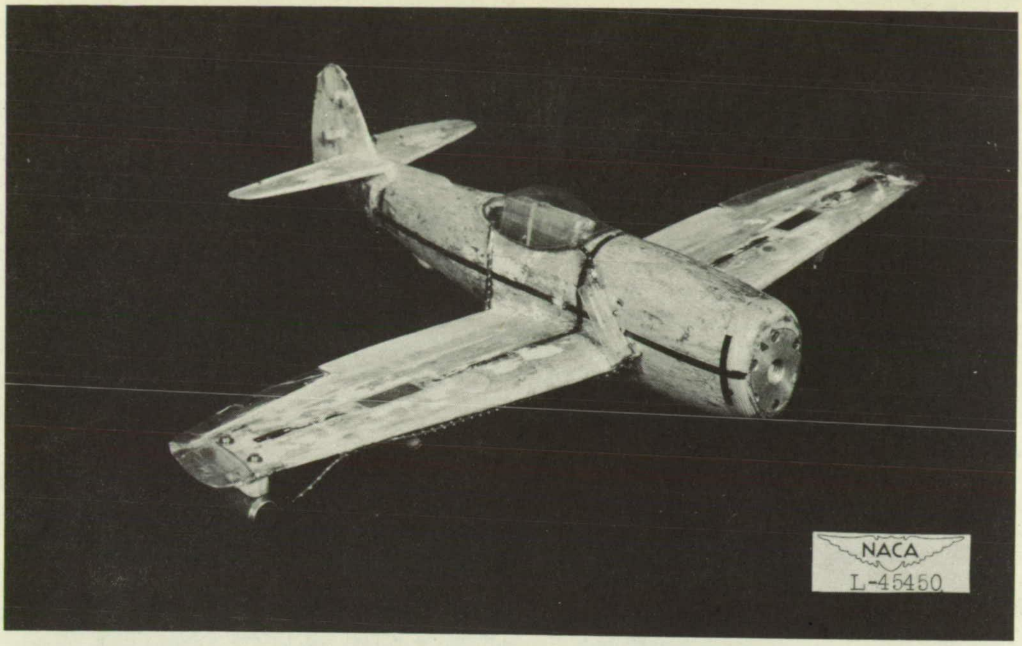

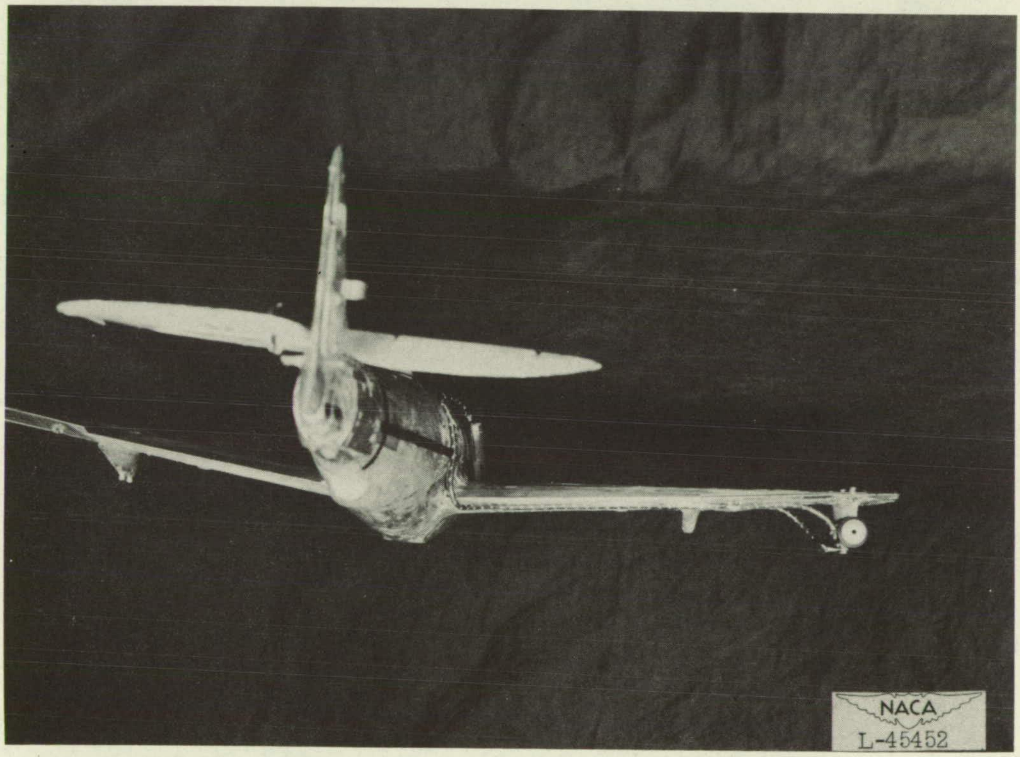

Figure 3.- Photographs of a $\frac{1}{25}$-scale spin-tunnel model with rocket installed.

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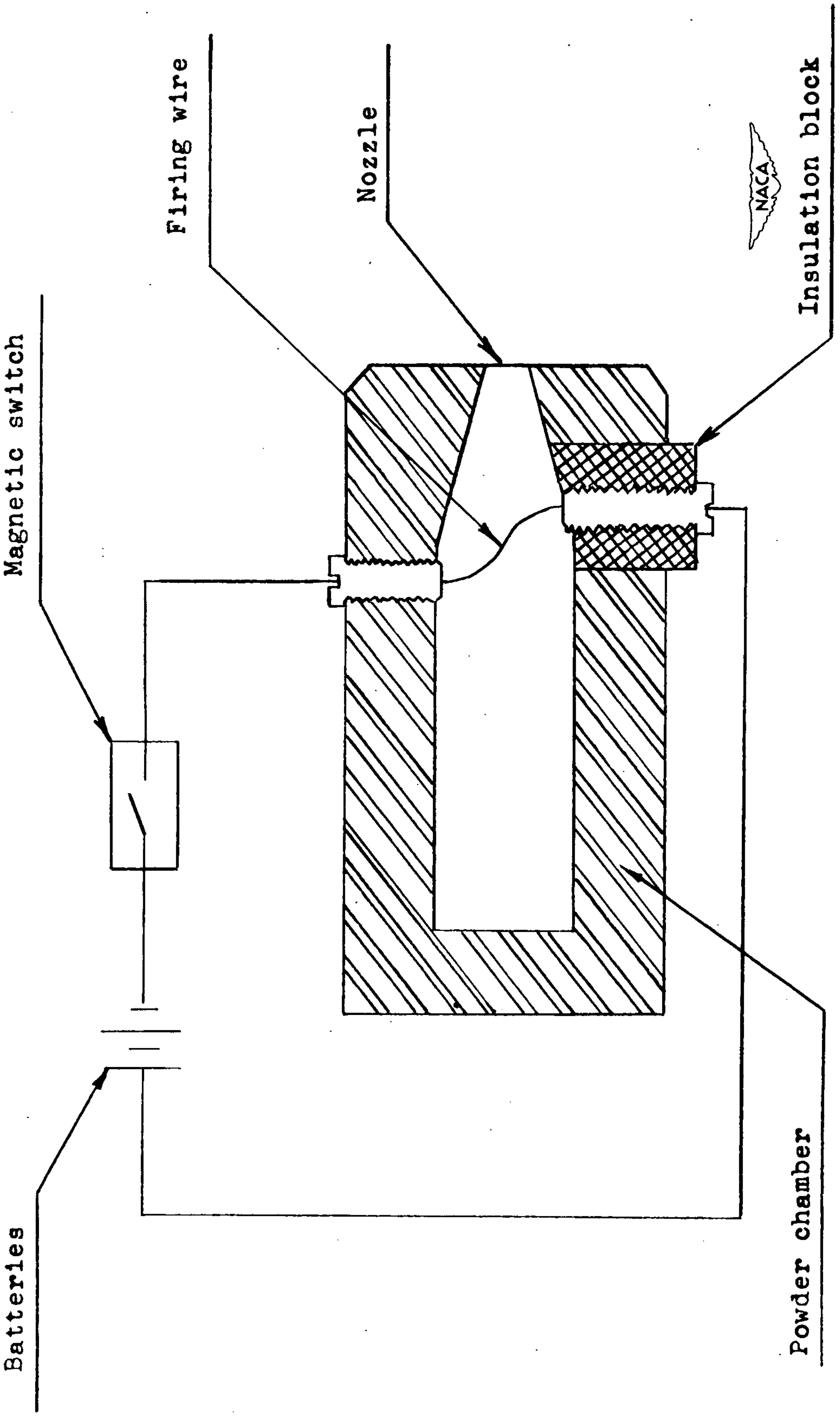

Figure 4.- Diagramatic sectional view of rocket used for recovery tests, showing electrical circuits.

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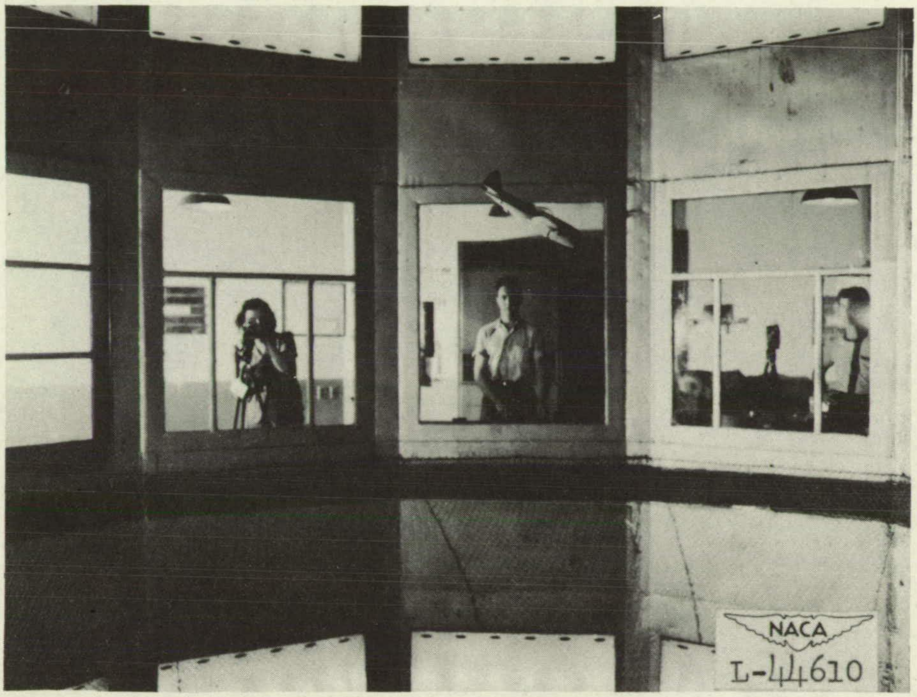

Figure 5.- Photograph of a $\frac{1}{25}$-scale model spinning in the Langley 20-foot free-spinning tunnel.

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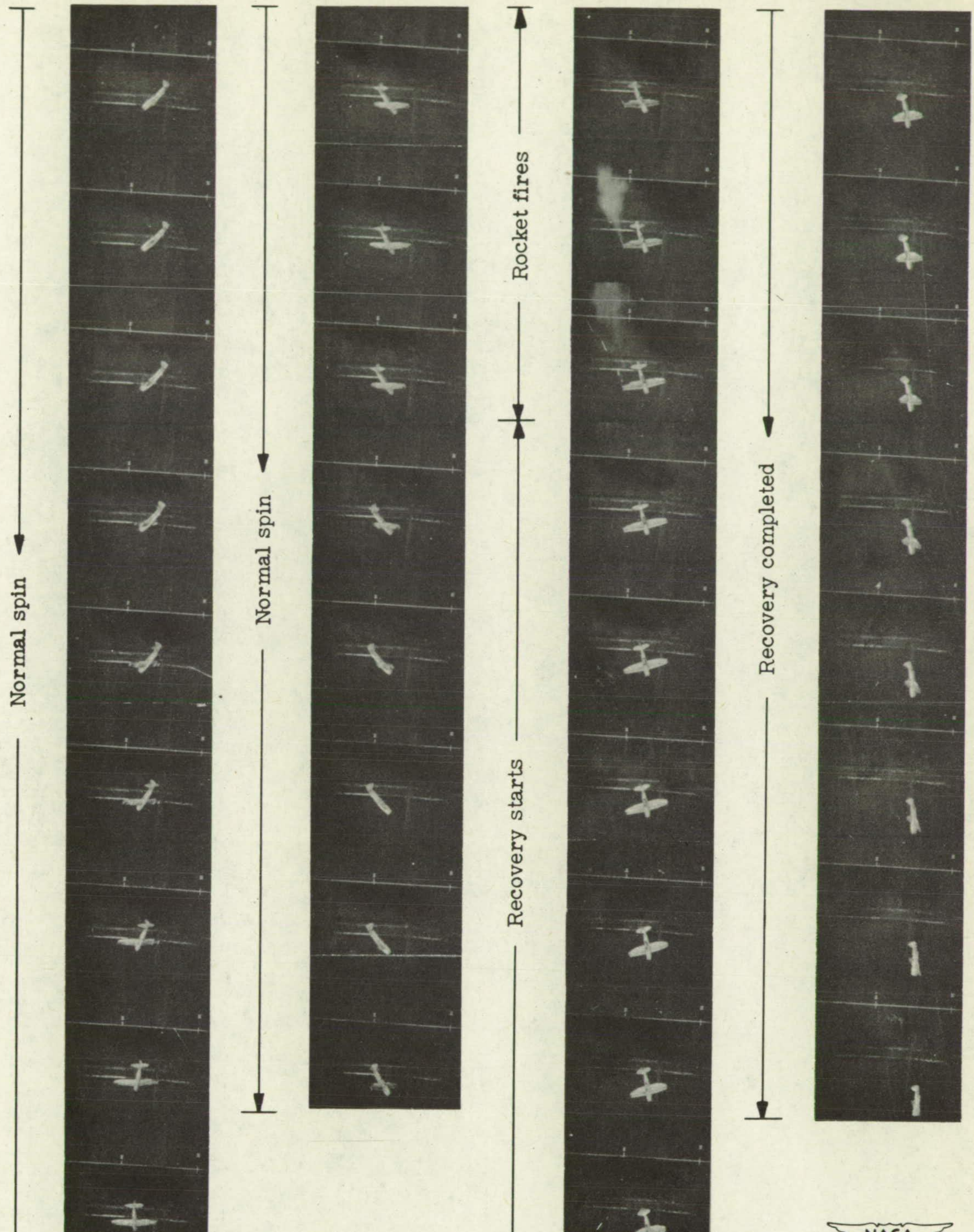

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Figure 6.- Photograph of a typical recovery from a right spin by use of a rocket fired rearward from the right wing of the model; 64 frames per second.